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(54) **Testing and calibration of electromagnetic flowmeters**

(57) An electromagnetic flowmeter is tested and calibrated in situ by measuring the resistance of an energising coil of the flowmeter and determining the inductance of the coil by measuring an exponentially changing current in the coil. Calibration accuracy of the flowmeter may also be assessed by comparison of the values of measured electrical parameters of the coil circuit with stored values. The isolation to ground impedance of the coil and the electrodes and the eddy current losses in the meter may also be measured.

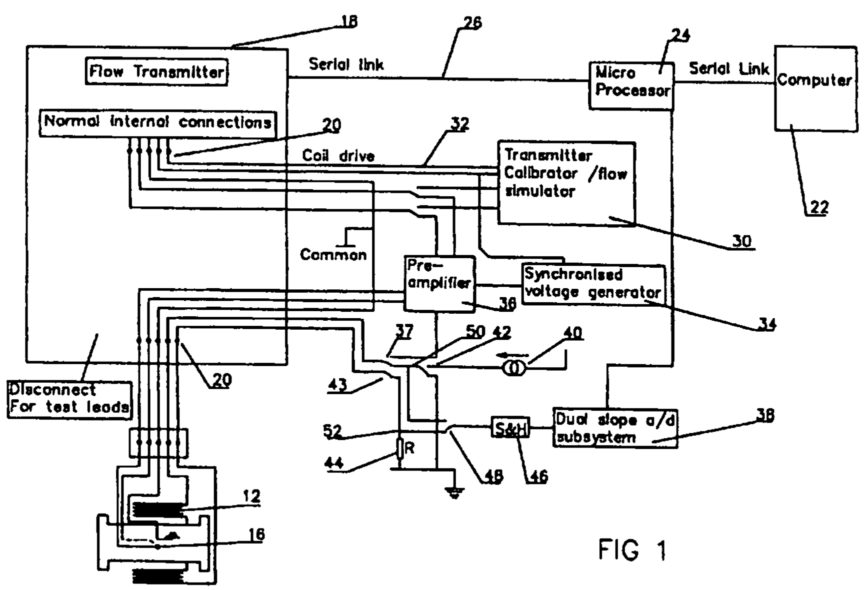

FIG 1

GB 2 309 308 A

At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

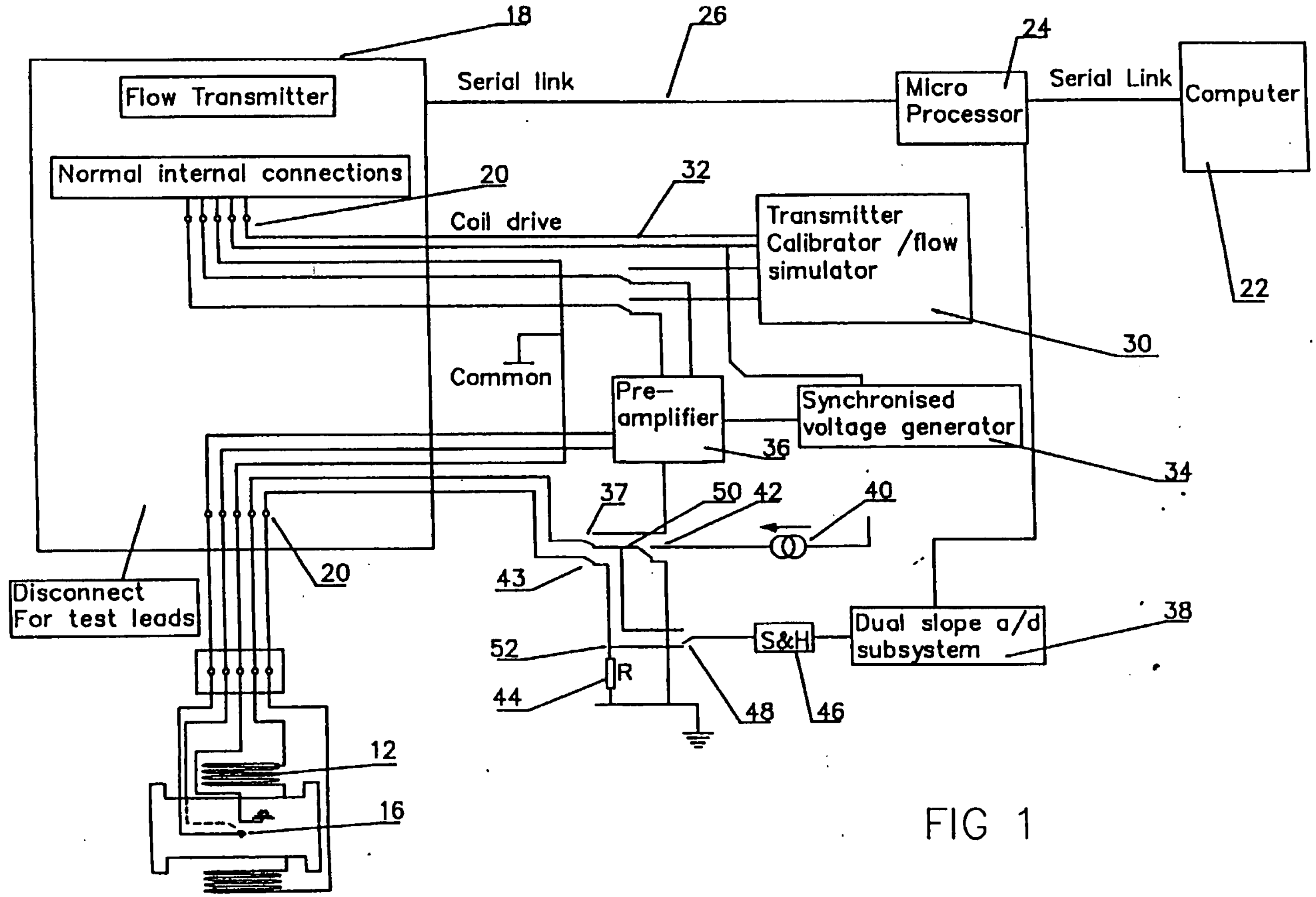
18
26
24
Serial link
Micro
Processor
Serial Link
Computer
Flow Transmitter
Normal internal connections
20
32
Coil drive
Transmitter
Calibrator /flow
simulator
22
30
Common
Pre-
amplifier
Synchronised
voltage generator
36
34
37
50 42
40
20
43
Disconnect
For test leads
Dual slope a/d
subsystem
38
52
S&H
R
44
48
46
12
16

FIG 1

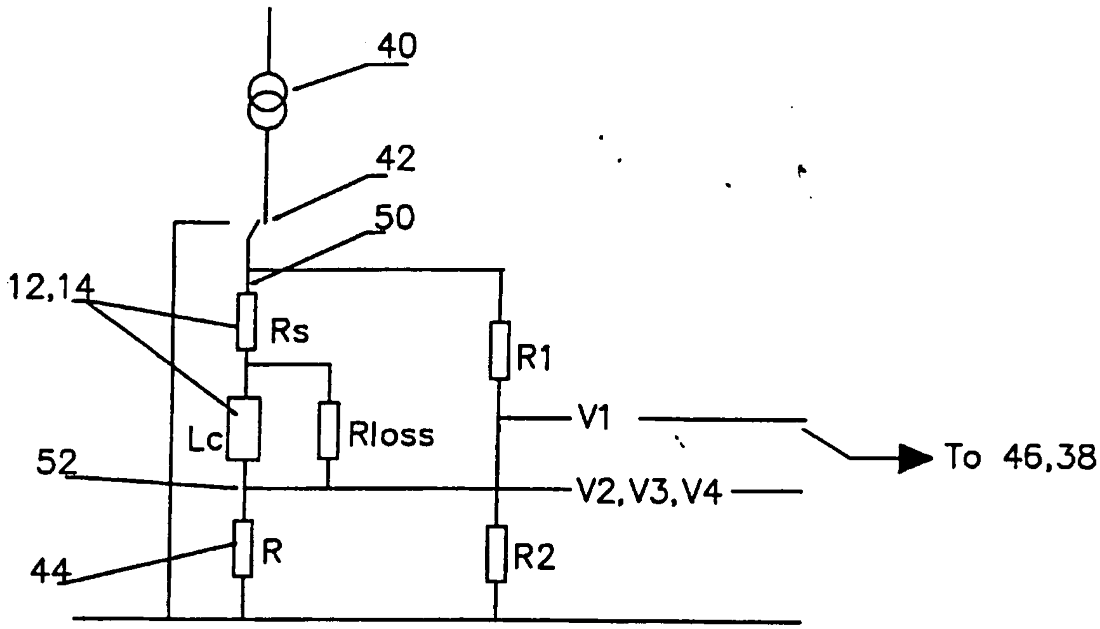
40
42
50
12,14
Rs
R1
Lc
Rloss
V1
To 46,38
52
V2,V3,V4
44
R
R2

FIG 2

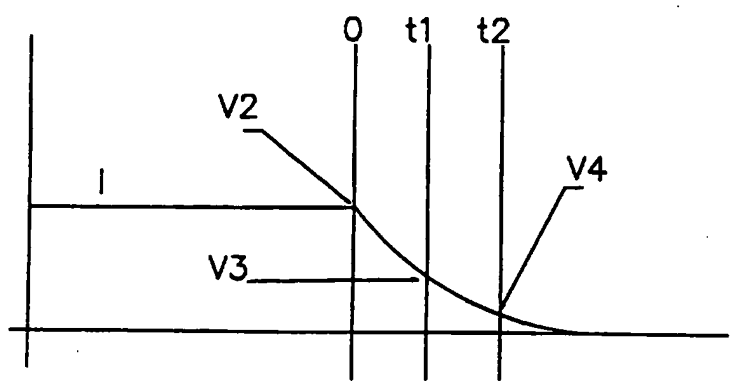
0
t1
t2
V2
I
V4
V3

FIG 3

/

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CALIBRATION OF FLOW METERS

This invention relates to the calibration of flow meters.

The increasing need of companies such as water utilities to comply with BS5750 (ISO9001) is forcing them to perform regular routine checks on all their equipment. In the case of a free-standing or hand held instrument this is not difficult; it is sent away to a calibration house annually for a calibration check and issue of an appropriate certificate. The case of an installed flowmeter is not so easy. The transmitter can be checked with a simulator which can itself be checked by the manufacturer to BS5750. The sensor however, at present, must be removed from the pipeline (and possibly from under the ground) and returned to a test facility for wet calibration checking.

Furthermore, in some markets such as the U.S.A. and Canada, there is some reluctance to accept electromagnetic flowmeters as measuring devices since currently they cannot be calibrated in situ. There is a preference for Venturi tubes, the performance of which can be measured directly.

It is an object of at least the preferred embodiments of the present invention to avoid the forgoing problem and perceived disadvantage of electromagnetic flowmeters.

In one aspect, the invention provides a method of in situ testing of an electromagnetic flowmeter comprising measuring at least two electrical parameters (preferably substantially independent parameters) of the sensor coil circuit, comparing the measured parameters to stored parameters, and determining whether the calibration of the flowmeter is accurate based on the results of the comparison. This may allow calibration drift to be assessed reliably.

The at least two electrical parameters preferably include a measure of ohmic resistance and a measure of inductance of the sensor coil; these parameters together may give

reliable characterisation of the coil. Impedance and other parameters are preferably measured according to one of the aspects below.

Optionally a measure of losses in said coil is used in said determining, for example in addition to ohmic resistance and inductance; this can further improve detection of of changes in the coil properties.

Preferably, the stored parameters comprise parameters measured from the same flowmeter at an earlier time. Storing parameters for an individual flowmeter, for example during manufacture or initial calibration, may enable a more accurate determination of changes in meter properties that is less sensitive to manufacturing tolerances.

However, the stored parameters may comprise parameters defined for a batch of said flowmeters, for example on the basis of mean or predicted parameters for a model or a batch of meters of a particular model; this reduces the amount of data that need be stored.

Determination of the parameters preferably includes measuring an exponentially-changing current (or related variable) through a coil and deriving a time-constant therefrom, for example according to one of the following aspects.

According to another aspect of the invention there is provided a method of in situ testing of an electromagnetic flowmeter comprising determining the ohmic resistance of an energising coil thereof, measuring an exponentially-changing current across the coil, or a variable related thereto, deriving a time constant therefrom and determining the inductance of the coil from the time constant and the ohmic resistance.

In an apparatus aspect the invention provides electromagnetic flowmeter testing apparatus comprising means for determining the ohmic resistance of an energising coil of the flowmeter, means for providing an exponentially-changing current in the coil, means for measuring said current or a variable related thereto, means for deriving a

time constant therefrom and means for determining the inductance of the coil from the time constant and the resistance.

The exponentially changing current may be produced by effecting a step change in a voltage applied to the coil.

The step change may be produced by removing the applied voltage.

Preferably the ohmic resistance is ratiometrically determined by reference to a resistor of known value in series with the coil.

The invention additionally may include measuring one or more of the following:

- the isolation-to-ground impedance of the sensor coil;
- the isolation-to-ground impedance of a sensor electrode of the flowmeter;
- the eddy current resistance or loss component of the flowmeter.

Thus the method may include repeating the measurement of the exponentially-changing current or a variable related thereto later in time than the first measurement, and employing the two measurements and the times thereof either to derive an eddy current resistance of the flow meter, or to correct the determined value of the coil inductance for the effects of said resistance.

The method then preferably comprises measuring the elapsed times at which the said measurements are taken after the step voltage change is effected, and utilising said elapsed times in said derivation of correction resistance.

In a further aspect the invention thus comprises a method of in-situ testing a flowmeter comprising measuring an exponentially changing current in an energising coil of the flowmeter or a variable related thereto at two known time intervals from a datum and deriving from said measurements and time intervals an eddy current resistance of the flowmeter.

In a yet further aspect the invention provides a method of testing an electromagnetic flowmeter comprising applying to a component thereof an AC test signal of a frequency equal to that of a drive signal applied to an energising coil of the flowmeter during normal operation thereof, said test signal producing in said circuit a response characteristic of an impedance of said component and measuring said response by means of sensing means of the flowmeter which during normal operation senses a signal characteristic of fluid flow through the flowmeter.

In yet another aspect there is provided electromagnetic flowmeter testing apparatus comprising means for applying to a component thereof an AC test signal of a frequency equal to that of a drive signal applied to an energising coil of the flowmeter during normal operation thereof, so as to produce in said circuit a response characteristic of an impedance of said component and means for supplying said response to sensing means of the flowmeter which during normal operation senses a signal characteristic of fluid flow through the flowmeter, whereby the sensing means measures said response.

The said component may be an electrode and the impedance may be the isolation impedance thereof.

Alternatively or in addition the component may be the energising coil of the flowmeter, and the impedance in the isolation impedance of the coil.

The AC test signal may be obtained from the drive signal.

The test apparatus of the invention may be packaged in portable form for use on site to test installed flowmeters.

The apparatus also may be incorporated into the flowmeter (which term includes its immediately adjacent drive and transmitter circuitry) and may be configured to operate automatically at intervals based either on time or on the total volume of fluid which

has passed through the meter. Thus a self-testing and self-calibrating meter can be provided.

The invention also provides apparatus for testing an electromagnetic flowmeter comprising means for measuring at least two electrical parameters of the sensor coil circuit, means storing predetermined values for said at least two electrical parameters, means for comparing the stored parameters to the measured parameters, and means for outputing an indication of whether the flowmeter is within calibration based on the results of the comparison. The output may be visual or audible, for example at the time of testing, or the results may be output as data, for later evaluation.

The apparatus is preferably arranged to carry out testing according to one or more of the above method aspects, and may incorporate further features of the above apparatus aspects.

The invention now will be described merely by way of example with reference to the accompanying drawings, wherein:

Figure 1 shows diagrammatically the testing of a flowmeter in accordance with the invention; and

Figures 2 and 3 illustrate a variation of the method of the invention.

In the drawing, a conventional electromagnetic flowmeter comprises a duct 10 through which a flow of conductive fluid to be measured passes, an energising coil disposed usually in two parts 12, 14 on opposite sides of the duct to generate a magnetic field in the fluid and a pair of electrodes 16 (only one shown) disposed orthogonally to the magnetic field to detect the voltage induced thereby in the flowing fluid.

The flowmeter is connected to a transmitter 18 which in normal use amplifies the output signal from the electrodes, perhaps performs preliminary signal processing, and delivers the signal to remote equipment. The transmitter 18 is often mounted on or adjacent to the pipe in which the meter is fitted.

The connection between the flowmeter 10 and the transmitter 18 is via a detachable connector 20 (shown separated) which enables field test equipment described hereafter to be interposed between the flowmeter and the transmitter. The test equipment also includes a portable (laptop) computer 22 and microprocessor 24 connected via a serial link 26 to the transmitter 18. The portable computer 22 is supplied with data, for example on a floppy disk, containing reference values of electrical parameters (ohmic resistance, inductance, insulation resistance) for the meter under test. These are supplied by the manufacturer, and are based on tests performed on the meter itself, or on model values for a range of similar meters.

For testing, the transmitter 18 is disconnected from the remote equipment to which it normally supplies its output, arrangements first having been made to ensure that the remote equipment is not deranged by the loss of the signal. For example, the computer can provide the remote equipment with a signal equal to the last output of the transmitter before interruption. The transmitter can then be tested and calibrated by supplying it with simulated inputs from a calibrator/simulator 30. The coil drive signal of the transmitter is converted by a resistor network into a voltage which can be varied on demand by the simulator 30. The transmitter coil drive signal for the energising coils 12 of the flowmeter also are supplied to the calibrator 30 for checking, via lines 32.

To test the flowmeter, the test equipment contains facilities to check the energising (drive) coil resistance, its inductance and its insulation (isolation to ground). The isolation of the electrodes 16 also is checked.

The test equipment includes a voltage generator 34 which derives an AC test current from the coil drive signal on line 32. The test current, which is synchronous with the drive signal, is applied to each electrode 16 in turn, the coil 12, 14 having first been disconnected. The resulting voltage developed at the electrode 16 is then measured by the transmitter 18 via a preamplifier 36.

Because the voltage is synchronous with the coil drive signal it is similar to the signal produced by the electrodes 16 when a flow is being measured. The transmitter then treats the voltage as a flow signal and produces an output on line 26 to the computer 22. Suitable calibration software in the computer converts the output to an indication of the isolation–to–ground impedance of the electrode 16. The test is then repeated for the other electrode.

A similar technique is adapted to test the isolation–to–ground impedance of the coil 12, 14. A voltage having the same frequency as the coil drive signal is applied by the voltage simulator 34 to the unterminated coil via a switch 37 and the resulting current to ground is measured by the transmitter 18 as if it were a flow measurement signal. The computer 22 interprets the transmitter output as the isolation to ground impedance of the coil.

The inductance of the drive coil 12, 14 is measured as follows:

A dual slope analog to digital converter system 38 is implemented by a standard analog subsystem chip in conjunction with the microprocessor 24. The inductance is measured by this system in three distinct phases.

1) The drive coil circuit 12, 14 is connected to a constant current source 40 via a relay 42. The current flows through the drive coil and returns to earth via a switch 43 and a resistor 44.A sample and hold amplifier 46 has its input connected via a switch 48 to point 50. The output of the sample and hold amplifier is supplied to the A/D converter 38. The sample and hold amplifier 46 operates in sample mode such that its output tracks its input at all times. The A/D converter 38 thus measures the total voltage across the coil 12, 14 and the resistor 44.

2) The sample and hold input is now connected via switch 48 to point 52. The A/D converter 38 now measures the voltage on resistor 44 only, at the same current. From the ratio of this voltage and the voltage measured in 1) above,

together with knowledge of the value R of resistor 44 the computer 22 can calculate the precise value of the resistance of the coil 12, 14.

3) The top of the coil circuit (point 50) is now disconnected from the current source and connected to ground via switch 42. The current in the circuit decays exponentially with a time constant of Lc/Rt, where Lc is the inductance of the coil, and Rt, is the total resistance of the circuit, including resistor 44. After a precisely timed interval (t), the sample and hold amplifier 46 is placed into its hold state, and the A/D converter 38 then measures the voltage stored by it. The current in the circuit at time t is given by:

$$i = I^{*} e^{(-t^{*} Rt/Lc)}$$

from which the inductance can be found as

$$L = -\ Rt^{*}t/\ln(i/I)$$

where L is the inductance of the coil 12, 14

Rt is the total resistance of the circuit

t is the time between the switch 42 grounding point 50 and the sample and hold amplifier to hold

i is the current measured at time t

I is the initial current

The inductance then can be found from the ratio of i and, the value of Rt having been ratiometrically determined from resistor 44. Hence the resulting measurement of inductance is not dependent on any circuit parameters other the reference resistor 44 and the precision of the time t, both of which can be controlled to the required degree of accuracy. Of course the A/D connector 38 must be sufficiently linear for the accuracy required.

If all of the foregoing tests give results within limits then it will have been established without recovering the meter from its pipeline that the flowmeter sensor coil and the transmitter are functionally correct, that the transmitter is within calibration and that the flowmeter sensor calibration has not drifted.

The test results are stored on disc by the computer, and an IS0900I (B5 5750) certificate is printed for retention by the meter user.

All of the test routines may be made automatic, and the necessary test circuitry (including computing capability equivalent to the PC 22) integrated into the transmitter 18, thereby giving the flowmeter installation a BITE (built-in test equipment) capability. Such equipment may be programmed to operate at pre-set intervals dependant on elapsed time or the total fluid flow past the meter if an integrating function is present. Alternatively the test routine may be controlled from the remote equipment to which the transmitter 18 is connected.

The test routine may be further refined as shown in Figures 2 and 3. In Figure 2, the resistive and inductive components of the energising coil are shown separately and respectively as Rs and Lc. Other components bear the same reference numerals as in Figure 1.

A relatively large voltage appears at point 50 across the coil 12,14 and resistor 44 when the switch 42 connects the coils 12,14 to the constant current source 40. This voltage may exceed the capacity of the sample and hold circuit 46 or the A/D converter 38, and therefore the voltage supplied to those components from point 50 via switch 48 is stepped-down to V_1 by a potential divider R_1, R_2. Voltage measurements from point 52 are taken directly, as in Figure 1.

As already described, the resistance Rs of the energising coil is determined from the ratio of the voltages at point 50 ($V_1 * \frac{R_1 + R_2}{R_2}$) and point 52 ($V_2$), under steady-state conditions.

The energising coil 12,14 can be considered as an ideal inductor L_c which has in parallel with it a resistive term Rloss which represents the heating losses due to eddy currents in the flowmeter tube. This assumes a coupling coefficient close to unity and thus is a simplification, but it still improves the accuracy of the determination of L_c, as will be apparent hereafter. The flowmeter tube is only coupled by transformer

action to the coil and under steady state conditions therefore all the current I flows through L_c. When the switch 42 is closed however, to disconnect the current source and short the coil to earth, the stored field collapses. Then the current flows through Rs and Rm, and by transformer action some flows through Rloss also.

By making measurements of the decay current at different times t_1 and t_2 as shown in Figure 3, we can derive two values of the inductance as below, but these must be equal:

$$L = \frac{-t_1 * V1/V2 * R/a}{\ln(a) + \ln(V3/V2)} = \frac{-t_2 * V1/V2 * R/a}{\ln(a) + \ln(V4/V2)} \qquad (1)$$

Where

$$a = \frac{Rs + Rloss + R}{Rloss} \qquad (2)$$

We can then derive from (1)

$$\ln(a) = \frac{t_1 * \ln(V4/V2) - t_2 * \ln(V3/V2}{t_2 - t_1}$$

and, substituting back

$$L = \frac{-t_1 * V1/V2 * R/a}{\ln(a) + Log(V3/V2)}$$

and from (2)

$$Rloss = \frac{Rs + R}{a-1}$$

First the measurement is made at time t_1 after closure of switch 42, and the values for V1, V2 and V3 are derived. The measurement is then repeated at a time of t_2, and values for V1', V2' and V4 are obtained. V1', V2' may be slightly different to V1 and V2 (due to drift in the constant current source with time), but the formulae are modified slightly below to accommodate this:

$$L = \frac{-t_1 * V1/V2 * R/a}{\ln(a)+\ln(V3/V2)} = \frac{-t_2 * V1'/V2' * R/a}{\ln(a)+\ln(V4/V2')}$$

$$\ln(a) = \frac{t_1 * \ln(V4/V2') - t_2 * \ln(V3/V2)}{t_2 - t_1}$$

Having thus determined Rloss, the calculation of L in paragraph 3 above can be repeated with the value of Rt revised to include Rloss.

Each feature disclosed in this specification (which term includes the claims) and/or shown in the drawings may be incorporated in the invention independently of other disclosed and/or illustrated features.

The text of the abstract as filed herewith is included in the specification by reference.

CLAIMS:

1. A method of in situ testing of an electromagnetic flowmeter comprising measuring at least two electrical parameters of the sensor coil circuit, comparing the measured parameters to stored parameters, and determining whether the calibration of the flowmeter is accurate based on the results of the comparison.

2. A method according to claim 1, wherein said at least two electrical parameters include a measure of ohmic resistance and a measure of inductance of the sensor coil.

3. A method according to claim 1 or claim 2, wherein a measure of losses in said coil is used in said determination.

4. A method according to claim 1,2 or 3, wherein the stored parameters comprise parameters measured from the same flowmeter at an earlier time.

5. A method according to claim 1,2 or 3, wherein the stored parameters comprise parameters defined for a batch of said flowmeters.

6. A method of in situ testing of an electromagnetic flowmeter comprising determining the ohmic resistance of an energising coil thereof, measuring an exponentially-changing current in the coil or a variable related thereto, deriving a time constant therefrom and determining the inductance of the coil from the time constant and the ohmic resistance.

7. A method as claimed in Claim 6, where the exponentially changing current is produced by effecting a step change in a voltage applied to the coil.

8. A method as claimed in Claim 7 where the step change is produced by removing the applied voltage.

9. A method as claimed in Claim 6, 7 or 8 wherein the ohmic resistance is ratiometrically determined by reference to a resistor of known value in series with the coil.

10. A method as claimed in any preceding claim further comprising measuring one or more of the following:

- the isolation-to-ground impedance of the sensor coil;
- the isolation-to-ground impedance of a sensor electrode of the flowmeter;
- an eddy current resistance or loss component of the flowmeter.

11. A method as claimed in any of Claims 6 to 9, comprising repeating the measurement of the exponentially-changing current or a variable related thereto later in time than the first measurement, and employing two measurements and the times thereof either to derive an eddy current resistance of the flow meter, or to correct the determined value of the coil inductance for the effects of said resistance.

12. A method as claimed in Claims 7 and 11, comprising measuring the elapsed times at which the said measurements are taken after the step voltage change is effected, and utilising said elapsed times in the said derivation or correction.

13. A method of in-situ testing a flowmeter comprising measuring an exponentially changing current in an energising coil of the flowmeter or a variable related thereto at two known time intervals from a datum and deriving from said measurements and time intervals an eddy current resistance of the flowmeter.

14. Electromagnetic flowmeter testing apparatus comprising means for determining the ohmic resistance of an energising coil of the flowmeter, means for providing an exponentially-changing current in the coil, means for measuring said current or a variable related thereto, means for deriving a time constant therefrom and means for determining the inductance of the coil from the time constant and the resistance.

15. A method of testing an electromagnetic flowmeter comprising applying to a component thereof an AC test signal of a frequency equal to that of a drive signal applied to an energising coil of the flowmeter during normal operation thereof, said signal producing in said circuit a response characteristic of an impedance of said component and measuring said response by means of sensing means of the flowmeter which during normal operation senses a signal characteristic of fluid flow through the flowmeter.

16. A method as claimed in Claim 15, wherein the said component is an electrode and the impedance is the isolation impedance thereof.

17. A method as claimed in Claim 15, wherein the component is the energising coil of the flowmeter, and the impedance in the isolation impedance of the coil.

18. A method as claimed in any of Claims 15, 16 or 17, wherein the AC test signal is obtained from the drive signal.

19. Electromagnetic flowmeter testing apparatus comprising means for applying to a component thereof an AC test signal of a frequency equal to that of a drive signal applied to an energising coil of the flowmeter during normal operation thereof, so as to produce in said circuit a response characteristic of an impedance of said component and means for supplying said response to sensing means of the flowmeter which during normal operation senses a signal characteristic of fluid flow through the flowmeter, whereby the sensing means measures said response.

20. An electromagnetic flowmeter having incorporated therein testing apparatus as claimed in Claim 14 and/or Claim 19.

21. Apparatus for testing an electromagnetic flowmeter comprising means for measuring at least two electrical parameters of the sensor coil circuit, means storing predetermined values for said at least two electrical parameters, means for comparing th stored parameters to the measured parameters, and means for outputing an

indication of whether the flowmeter is within calibration based on the results of the comparison.

22. A method according to any of claims 1,2,3,4 or 5, wherein measuring at least one of the parameters includes measuring an exponentially changing variable selected from the group consisting of: a voltage across a coil, a current through a coil, a variable indicative of said voltage or current; and determining a time constant therefrom.

23. A method substantially as herein described.

24. A testing apparatus or an electromagnetic flowmeter having testing apparatus incorporated therein substantially as herein described.

25. A testing apparatus or an electromagnetic flowmeter having testing apparatus incorporated therein substantially as illustrated in the accompanying drawings.

The Patent Office

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Applicati n No:	GB 9700937.7	**Examiner:**	Mr A Oldershaw
Claims searched:	1 to 5, 21 and 22	**Date of search:**	8 April 1997

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.O): G1N NCVE, NCVG

Int Cl (Ed.6): G01F

Other: Online: WPI

Documents considered to be relevant:

Category	Identity of document and relevant passage	Relevant to claims
A	GB2236394A (HEMP)	
A	US5207105 (FUKUNAGA)	
A	US4520650 (PALMER)	

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.